The Use of Virtual Reality at Boeing's Huntsville Laboratories.

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This paper briefly describes some of the Virtual Reality (VR) and Visualization efforts at Boeing's Advanced Computing Group in Huntsville Alabama. Boeing's Huntsville labs are primarily focused on supporting aerospace and defense efforts including several NASA and DoD projects. For example Boeing design engineers are currently working on three of NASA's major development efforts: the Space Station Freedom (SSF) scheduled to begin deployment in 1996 (Figure 1); return missions to the moon including base camps and long term visitation; and the first Mars mission. As one might expect, Computer Aided Design (CAD) systems are playing a major role in these efforts. In order to better support and augment the current CAD design process and analysis tasks, the use of VR and visualization are being tested and used at Boeing's Huntsville facilities.

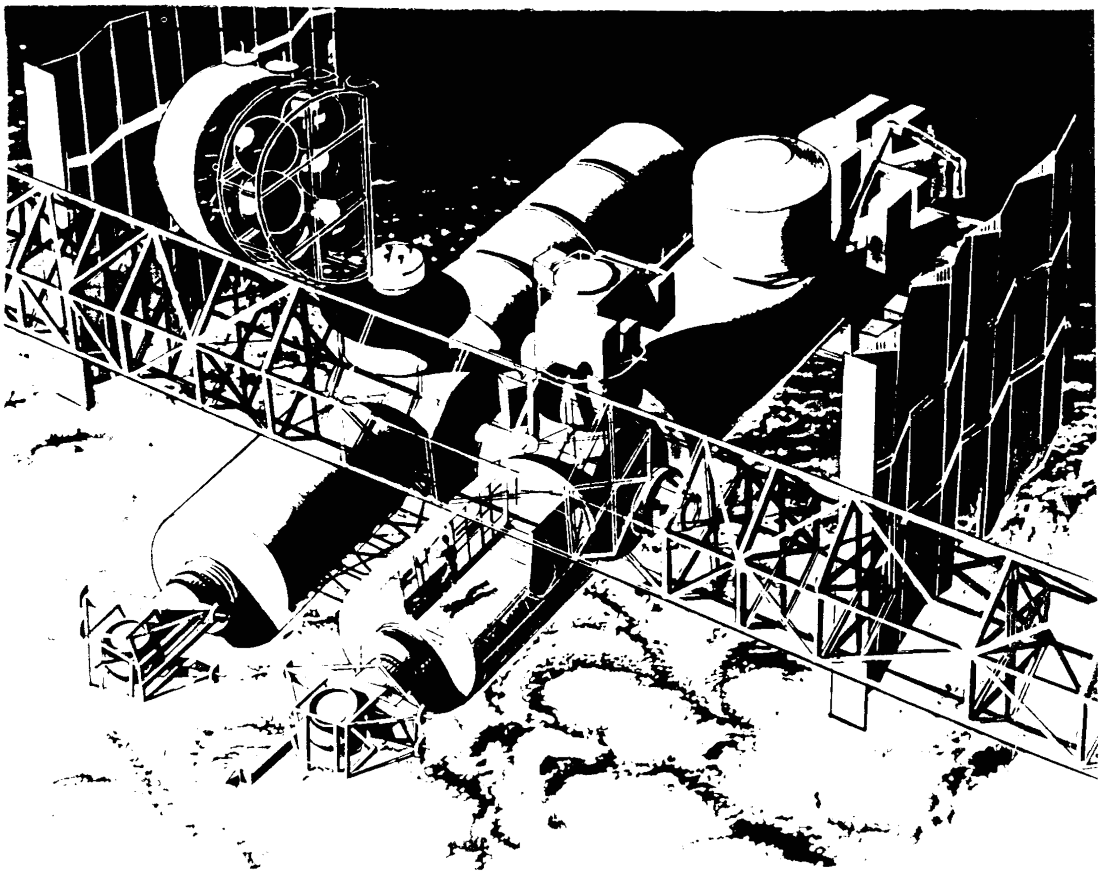

Figure 1: Space Station Freedom

Visualization of CAD Design Data

To date, our most successful efforts have been in the area of simple three dimensional immersive viewing of CAD data. The use of eyephones and pointing device allow a user to move at will through design files and study the overall systems, subsystems and assemblies. These include the Space Station Freedom, lunar rover (Figure 2) and base camp designs and planetary terrain models. The size of most of these systems is quite large, on the order of several 100 megabytes of CAD data.

Since our eyephones are of limited resolution and are limited to only one user at a time, we've found that viewing the same information in a non-immersive manner is quite effective as well. By viewing the models via a projection system we loose the 3D immersion, but we are able to show high-resolution graphics to large numbers of people. We can thus take a group of people through an inspection of a design. This type of system was used at the Space Station Freedom Critical Design Review in February of 1993 where several hundred people were able to view a trip through the Space Station in an interactive manner.

The current system offers only immersive viewing of static data. While the user may move about at will, there is no behavior or kinematics associated with any of the viewed objects. The system is strictly a design review tool which can be used for example, to find interferences and other flaws early in the design process while corrective action is still fairly inexpensive. Other efforts have focused on more interactive visualization

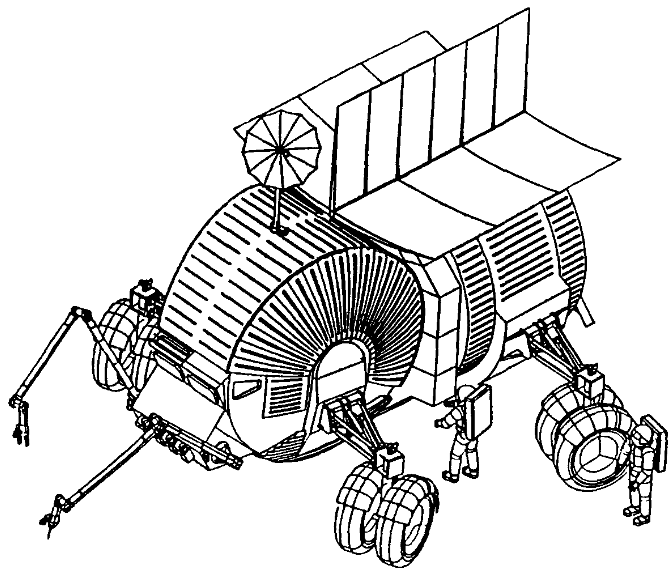

Figure 2: Sample Lunar Rover Design

Lunar Radiation Effects Model

One of these projects is a lunar rover radiation effects model. The Advance Civil Space Group (ACS) here in Huntsville is in the process of designing lunar and Mars rovers for future manned missions. These rovers are slated to be the vehicle of choice once an astronaut is on the surface of one of these bodies. The pressurized environment offered by these rovers are a far cry from the open cockpits used on the original Apollo lunar missions. Figure 2 shows one such award winning design by Buddy Tanner of ACS. One of the problems that must be addressed in the design of these machines is radiation levels, especially during a solar proton event when

dosage rates may rise dramatically. Radiation analysis experts such as ACS's Matthew Appleby are tasked to make sure the rovers have adequate shielding for humans during such an event. VR is being used to allow the designers and analysts into their models where they can observe first hand the dosage levels of both primary and secondary radiation coming from the various surfaces within the rover. In this way, the designers can easily see where the problems areas are and go back to the original CAD design to work on resolving the hot-spots. This information is visualized by a color coding scheme where "warm" colors represent the highest dosage and "cool" colors the lowest.

While the entire rover design is being brought into the VR model, only the airlock (which is where the astronauts are slated to go during a proton event) is analyzed for radiation levels. Each object upon which an analysis is to be done has a behavioral attribute that allows the object to calculate what color it should be. This is based upon the thickness of the object and the location of the astronaut. Note this information can be (and is being) calculated by other means. VR is being used to let the designers "see" the data in a new way and in real-time. Instead of looking at tabular data, the designer can move around the model and get a visual feel for the problem areas.

The modeling capabilities of the VR systems being used for this particular project are not as complex and sophisticated as those of most CAD systems. The capabilities of these tools has led to some limits on exactly what can be modeled. For example, most CAD systems have solid object models, while this VR system generally just models the surfaces of an object. It also has trouble modeling realistic curved surfaces as well, relying instead on a close approximation using flat surfaced polygons. In addition, it is a stand-alone tool that does not interface well with other CAD systems.

These and other issues had a great impact on the lunar rover radiation effects VR model. For example, several attempts were made to bring in the rover CAD designs directly. A path was found to bring in parts of the design, but problems with polyline definitions still plague the effort. The outer shell of the cockpit and the wheel assemblies did translate into the VR system and are used as reference points for the user. This is because the users discovered it helps them to feel immersed in the system if they can see the entire rover. The areas that required behavioral attributes are modeled separately and overlaid onto the translated areas of the rover.

The airlock area of the rover is a cylindrical room which is modeled in the VR world as a series of many small squares. (Figure 3 shows a cross-section of the object representation of the airlock area.) Each of these squares has an associated thickness value. This value represents the equivalent aluminum density of that area of the airlock. This number is calculated beforehand by taking all of the components that comprise that area (water tanks, electrical lines, oxygen tanks, etc.) and deriving the amount of aluminum that would yield the same amount of radiation protection. This precalculation allows the system to use one set of formulas to determine the radiation amounts rather than a series of complicated calculations based upon each of the materials used in the rover. The fidelity of the model is increased as the number of squares used increases. Currently, due to computational limitations, each square represents about a six inch by six inch area within the airlock. As the ability of the modeling system increases, the area of each object should be dropped to be about one inch square.

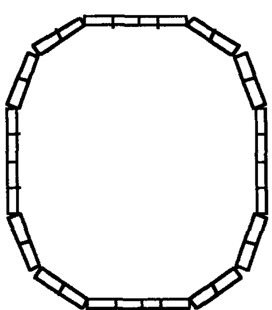

Figure 3. A cross-section of the modeled lunar rover airlock.

To calculate the amount of primary radiation a user receives from a given surface, a fairly straightforward formula is used based upon the thickness (aluminum density) of the surface object, the angle of the user to the flat side of the surface and the amount of radiation coming from outside the rover (figure 4). The simplified version for a given wall object sitting along the X axis is: The user's orthogonal distance from the modeled object (the X axis distance) divided by the absolute

distance from the modeled object (thus yielding the cosine of the angle shown in figure 4) multiplied by the equivalent aluminum density of the given object and the current radiation dosage level. This calculation yields a number that can then be scaled and used to generate an appropriate color for the object to display. The initial system simply uses this scaled number to determine how much red or green add to the object's color. The current system is able to make these calculations about 10 times per second for each object.

1) Calculate the traversal length of each vector

2) Use those to calculate the radiation effects from a given surface

3) Color code each surface based upon its calculated radiation effect

The most important components of the Primary Effects calculation are:

The Cosine of the attack angle and

The Equivalent Aluminum Density of the object

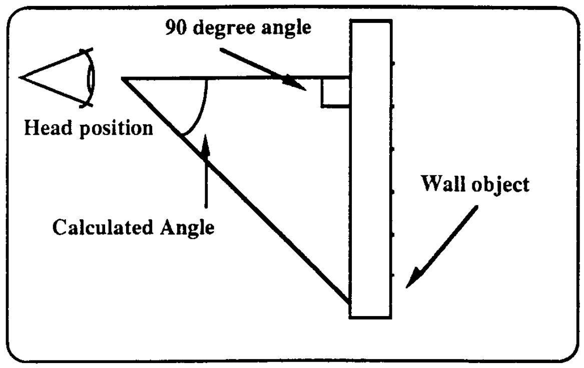

Figure 4: The calculation of radiation amounts

The amount of secondary radiation (that is, the amount of other radiation generated as a result of the passage of primary radiation through the rover's shell) is a bit more involved but uses much of the same information.

As the user moves around within the airlock area using a pair of eyephones and dataglove, the surface objects change color to reflect the amount of radiation the user is receiving. As the angle of the user to a given surface increases, the less radiation the user receives from that surface. As expected, to minimize exposure, the user should attempt to remain directly in front of thicker areas and increase their angles with thinner areas. Another aspect, which is not as intuitive, is that when considering an entire wall, the closer the user is to the wall, the less radiation the user receives from it. This is because of the increased angles the user has in relation to most of the wall's objects. The system allows the user to see where the safe areas are, and allows them the chance to see if they can actually fit into such an area. An aggregate object is also modeled that the user may watch to see the total dosage from all surfaces.

Experiments with allowing the user to change settings while within the model are also being conducted. For example the user may change the thickness of a surface or the amount of radiation incident on the rover. These types of changes involve a little more interaction with the user, since they now have the ability to do more than simply move around. It's this type of interaction while totally immersed in a virtual environment that may one day lead to the ability to do real design work from within the VR world rather than just visualizing existing designs.

Human Factors, Maintenance and Operations on Space Station Freedom

Another area of application for VR in Huntsville deals with the interactive and immersive modeling of man/machine interfaces. For example, the design of the Space Station Freedom and

DoD projects make extensive use of CAD/CAM capabilities and prototype studies. If a designer could enter the models themselves, they could test their ideas without having to build expensive physical models. If the design shows that a human should be able to reach around a set of cables and easily access a back panel, VR offers an inexpensive preliminary test to verify that this is true. Of course physical prototypes will need to be built in the end, but VR offers the chance to eliminate some of the more glaring problems before they get too expensive to correct. Analytical models may also be reused at a later point in time for training and operations planning purposes, further reducing costs.

One such project currently underway is a study of crew maintenance of Space Station rack equipment. The laboratory module of SSF contains many racks of equipment that require various levels of maintenance. Fairly corse studies of maintenance procedures are accomplished using current VR equipment. The resolution, speed and tracking accuracy of our current equipment is not good enough for training of maintenance procedures yet. However, maintenance and operations plans can be studied before more intense zero-g testing using full sized physical prototypes in either the neutral buoyancy tank (figure 5) or on a KC-135 flight, both very expensive operations.

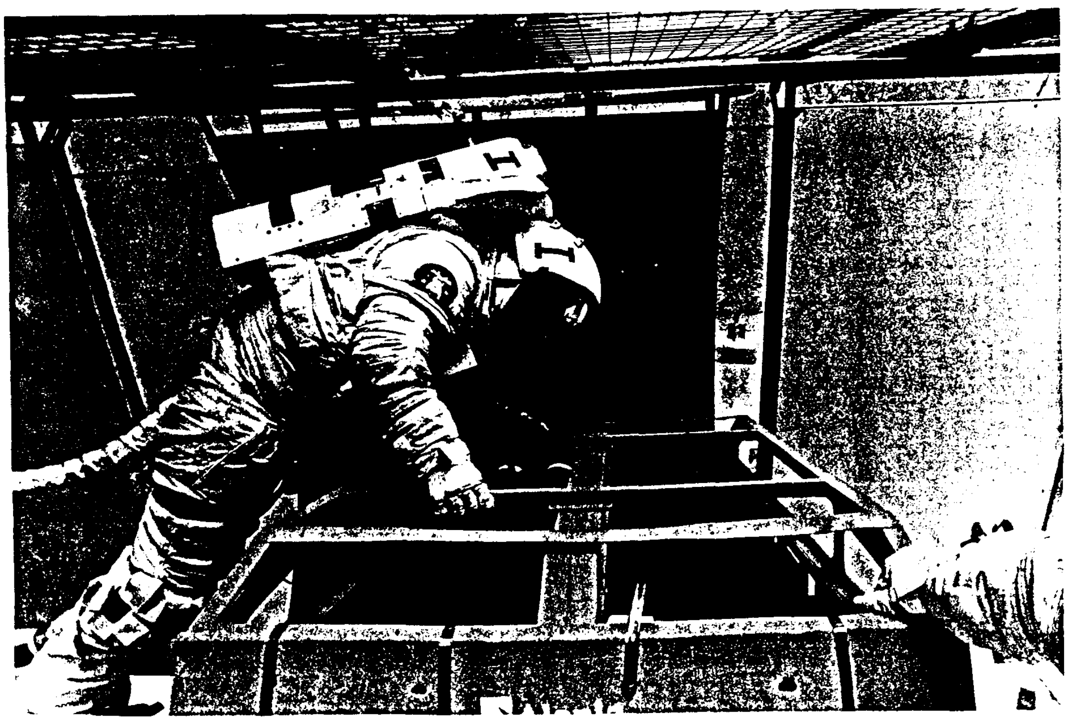

Figure 5: Use of the Neutral Buoyancy Tank

Another such project is a human-factors study in which the goal is to bring the engineering design documents into the virtual world and support the designers in analytical verification of their human engineering requirements. Initially such things as color schemes and lighting placement are being studied. As the models become more sophisticated, human interaction comes into play. We plan to insert models of different classes of humans into the system to

study the man/machine problem areas. For example the user of the virtual world would be modeled as a fifth percentile Japanese female or a ninety fifth percentile American male. (The physical characteristics of these sorts of groups are indeed known and modeled). Then the user can see if they can reach areas and do things based upon their modeled physical characteristics. As with the previous project, the only way to currently test such models is to build a full sized prototype.

Telerobotic Operations on Space Station Freedom

We are building a prototype system for driving Space Station based robotics. The robotic equipment that is being studied is slated to be used in a maintenance role, primarily during the unmanned periods on the Space Station. There are currently two robotic designs being built in a virtual world. The first is a spider like "wall-walker" which is controlled by a user wearing eyephones and one dataglove. The user views the robot from outside (i.e. the user is not projected into the robot as in a standard telepresense operation). To manipulate the robots legs, the user simply grabs one, moves it, lets it go and grabs another. The second robot being modeled does involve projecting the user into the robot. In this case, rack operations are being studied by allowing the robot to mimic the user's arm and hand movements. Our initial efforts have been to simply model the robotic operation with an eye toward operations planning. As the robot designs become more formal and prototype units are built, we plan to drive the actual machines. This should prove more interesting that moving a computer model about. Links to external robotic modeling systems are being studied as well.

Merging VR with Other Tools

With an eye toward the day when the VR hardware improves to the point that we can use it as a fully integrated extension to current CAD efforts, we are looking at how to tie VR modeling tools in with other systems. One primary focus is to use VR as a front in to fairly sophisticated model based reasoning tools such. The idea is that VR should not reinvent a behavior modeling paradigm when there already exists a rich source of experience. Since the basis of most model based reasoning efforts is to model the low level behavioral attributes of components, it makes since to use the readily available tools.

Conclusions

Our long term goals of complex user interaction within the virtual world are fairly ambitious given the state of VR equipment today, but some of the simpler tasks are approachable now, and the technology is improving at a substantial rate. The primary problems with the current technology result from shortcomings in both the hardware and software. As stated earlier, speed and resolution of the visual displays and lack of fidelity in the dataglove or other pointing devices are the primary hardware problems. These are steadily improving but problems with the software side may take a little longer. The modeling capabilities of current VR systems is woefully inadequate and links to other more sophisticated modeling tools is not yet readily available. For example links into rule-based systems or physical systems modeling tools which could be used to model object behavior is not easily accessible. Kinematics and behavioral information stored within current CAD systems is also difficult to obtain. A true merging of VR with other techniques, which seems on the surface to be such an intuitive match, has not come to pass.